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Generation of Visible Radiation in Periodically Poled, Nearly-Stoichiometric Lithium Tantalate

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Abstract

Stoichiometric lithium tantalate (SLT) has been identified as a promising alternative to congruent lithium niobate as substrate material for quasi-phasematched (QPM) nonlinear optical frequency conversion. The advantages of SLT include superior resistance to optical damage, greater ultraviolet transparency, and a lower coercive field which should facilitate the fabrication of thicker periodically poled chips. We report the generation of 16 W of average power at 589 nm by single-pass sum-frequency generation of two Nd:YAG lasers in undoped, nearly-stoichiometric, lithium tantalate. Material which is grown directly from the melt, and which is not doped, therefore has the potential to be useful in applications (such as laser guide-star generation for adaptive optics, or projection displays) which require powers of 10 to 20 W in the visible.

1. Introduction

The potential advantages of SLT were noted after the first successful attempts to grow crystals of this material in a manner suitable for volume production [1]. Generation of 5 W of average power at 532 nm has been carried out using nearly-stoichiometric lithium tantalate that was grown by vapor transport equilibration (VTE) to form a material called VSLT and periodically poled [2]. Because perfect stoichiometry is difficult to achieve using conventional crystal-growing techniques, commercially available material deviates from the ideal composition. Magnesium doping is often used to improve the damage resistance of nearly-stoichiometric material. For example, generation of 7 W of average power at 532 nm was carried out in periodically poled, nearly-stoichiometric lithium tantalate doped with magnesium oxide [3]. We report the generation of 16 W of average power at 589 nm in undoped, nearly-stoichiometric, lithium tantalate. Material which is grown directly from the melt, and which is not doped, therefore has the potential to be useful in applications requiring high average powers in the visible, including the creation of laser guide stars for adaptive optics.

2. Experimental

Periodic poling was carried out at Physical Sciences Incorporated on a 76.2 mm diameter, 0.5 mm thick wafer of undoped, nearly-stoichiometric lithium tantalate provided by Deltronic Crystal Industries, using a poling procedure that has been described elsewhere [4]. The entire wafer was patterned in a single high-voltage pulse to create quasi-phasematching (QPM) gratings with periods between 5.8 μm and 11.2 μm . The coercive field, defined as the field at which a detectable poling current began to flow, was 2.5 kV/mm. Although this coercive field is much

lower than the coercive field of congruent lithium tantalate (~ 22 kV/mm), it is significantly higher than the lowest coercive field which has been measured on VSLT, less than 100 V/mm [2]. Since the coercive field is known to increase as the deviation from perfect stoichiometry increases, the material used in this work was significantly further from stoichiometry than VSLT. Several chips useful for nonlinear optical experiments were diced from the wafer and polished. One of these chips, with a length of 20 mm, was used to generate 589 nm radiation. The chip contained 8 QPM gratings with periods ranging from $10.5\text{ }\mu\text{m}$ to $11.2\text{ }\mu\text{m}$ in increments of $0.1\text{ }\mu\text{m}$. Anti-reflection coatings were deposited on the end faces of the chip.

Sum-frequency generation (SFG) experiments were performed on the coated chip at Coherent Technologies, Incorporated. Two different mode-locked Nd:YAG laser systems were used: one consisting of an oscillator at 1064 nm, and one consisting of an oscillator and a double-rod amplifier at 1319 nm. The repetition rate for each laser system was 80 MHz, while the respective pulse lengths were variable in the range 500 to 700 ps. The lasers were each focused to a FWHM beam diameter of $60\text{ }\mu\text{m}$. The average power transmitted through the exit face at 589 nm was measured as a function of the total near-IR average power incident upon the entrance face. For total near-infrared average powers of 33 W or less, the average powers in the near-IR beams were balanced to ensure that the average number of photons per second was approximately the same at both wavelengths. At that point the average power delivered by the 1319 nm laser system (~ 14.8 W) could not be increased further. Therefore, the photon-balance condition was not maintained for total near-infrared powers greater than 33 W. The crystal temperature was re-optimized at each power level, and was typically 1 to 2 °C lower at the highest power levels than it was at the lower power levels. The conversion efficiency (transmitted visible power divided by total incident near-IR power) was calculated at each power level.

3. Results

Results for a QPM grating with a period of $10.8\text{ }\mu\text{m}$ on the 20 mm long chip are shown in Figure 1. The average power at 589 nm increases monotonically with increasing near-IR power, reaching a maximum value of 16 W at a total near-IR power of 37 W. The conversion efficiency reaches a maximum value of 45.1% at a total near-IR power of 34 W, then declines slightly at higher near-IR powers. This decline can be attributed to the lack of photon balance at the highest near-IR powers, leading to depletion of the 1319 nm beam and back-conversion. A summary of the experimental conditions at the highest power level is given in Table 1. The QPM grating with a period of $10.8\text{ }\mu\text{m}$ was subjected to lifetime testing, maintaining a stable transmitted output power of >11 W at 589 nm during four separate 14-hour runs. The beam quality at 589 nm was also stable during these lifetime tests, with M^2 values of 1.1 and 1.5 in the two transverse dimensions. Similar results were obtained for a QPM grating with a period of $10.7\text{ }\mu\text{m}$, which had a phase-matching temperature of 88° C. The phase-matching temperatures for both QPM gratings were significantly lower than the values predicted by the published Sellmeier equation for nearly-stoichiometric lithium tantalate [5].

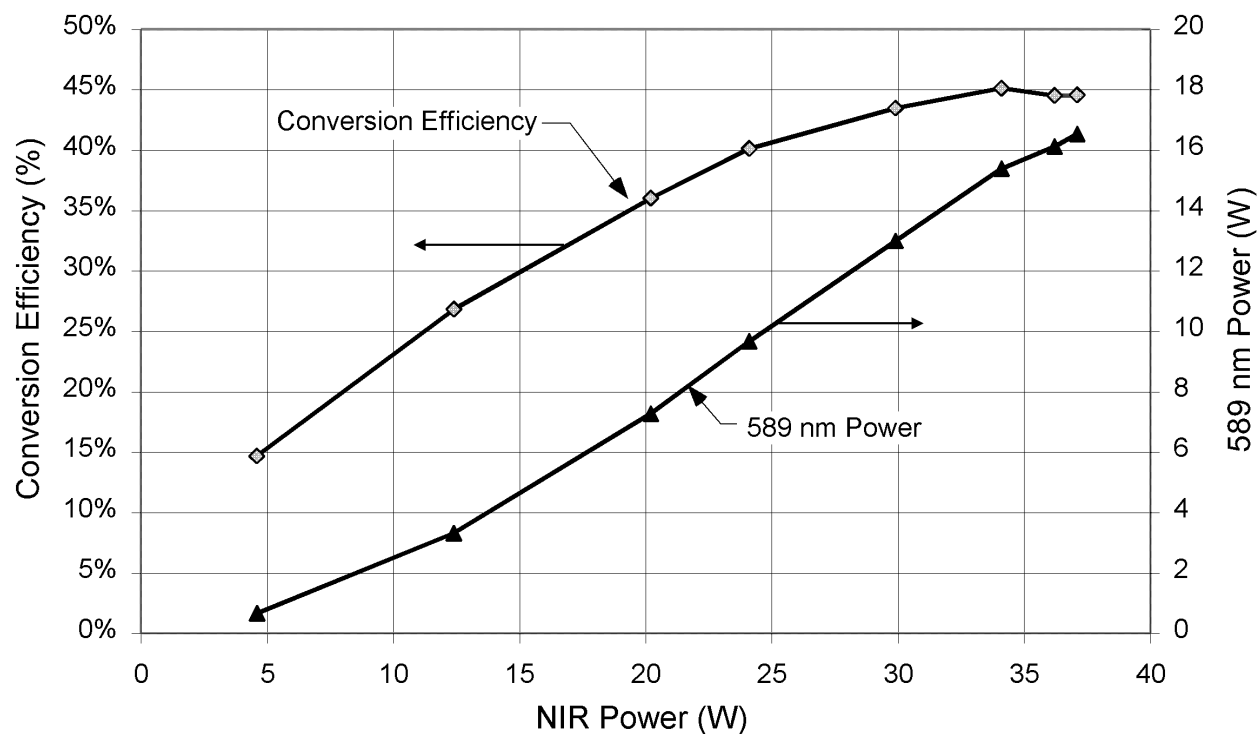


Figure 1. Conversion efficiency and 589 nm power as a function of total near-IR power for a QPM grating with a period of 10.8 μm . The phase-matching temperature was 45° C.

Table 1. Summary of Experimental Parameters

Quantity	Value
Repetition rate (@ 1064 nm and 1319 nm)	80 MHz
Average power @ 1064 nm	22.3 W
Average power @ 1319 nm	14.8 W
Average power @ 589 nm	16.5 W
Conversion efficiency	45%
Pulse length @ 1064 nm	600 ps
Pulse length @ 1319 nm	510 ps
Beam diameter (@ 1064 nm and 1319 nm)	60 μm FWHM
Length of QPM crystal	2.0 cm
Thickness of QPM crystal	0.5 mm
QPM period	10.8 μm
Phase-matching temperature	45° C

4. Summary and Conclusions

Periodically-poled, nearly stoichiometric lithium tantalate has been used to generate 16 W of average power at a wavelength of 589 nm, through a process of SFG using two mode-locked Nd:YAG lasers. To our knowledge this is the highest average power which has been generated at this wavelength in a QPM material. This result was achieved using a crystal with a thickness of 0.5 mm. Scaling to higher average powers should be possible once thicker crystals with the appropriate QPM period, and more powerful drive lasers, become available. This result is significant for two reasons. First, it demonstrates that nearly-stoichiometric lithium tantalate which is grown directly from the melt, and which is not doped, has the potential to be useful in applications which require powers of 10 to 20 W in the visible. Second, the average power, long-term stability, and beam quality of a 589 nm laser system based on this material have been shown to meet the requirements for adaptive optics in astronomy, leading to a successful installation of the laser system by Coherent Technologies at the Gemini North Observatory in Hawaii. Because this laser system is based on single-pass SFG in an extracavity nonlinear crystal, it offers an interesting alternative to the most powerful laser guide-star systems available today, which are based on intracavity SFG in lithium triborate [6].

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